

STEEL



COLLIER



DUQUESNE FURNACES



35 CENTS

COPYRIGHT, 1910
BY
ARTHUR L. COLLIER

32

©GLA271465

TN 130
.C7

P R E F A C E

I have written this brief treatise on steel, believing that such an article would appeal to many of the daily workers in this metal who desire to better inform themselves of its nature.

The first part concerns the principle methods by which steel is made; the second its structure and characteristics under different conditions.

Preceding the subject in hand are given a few definitions of certain terms used in the book.

ARTHUR L. COLLIER.

30

DEFINITIONS

Allotropic Forms: The different modifications in which an element may occur.

Example: Diamond, charcoal, graphite, forms of carbon
Alpha, beta, and gamma iron: forms of iron.

Alternate Stress: That stress produced in a body by bending it back and forth so that its fibres are alternately under tension and compression.

Carburizer: A substance, usually spiegeleisen or ferro-manganese, added to molten steel for the purpose of increasing the carbon content and of purifying the metal.

Chemical Symbol: An abbreviation, that is used to denote elements or compounds.

Example: Manganese=Mn; Manganese sulphide=MnS.

Compound: A chemical combination of two or more elements.

Example: Iron carbide, manganese sulphide.

Elastic Limit: The number of pounds per square inch of cross section at right angles to the strain, at which stress ceases to be proportional to the strain.

Element: A substance which has never been decomposed.

Example: Iron, Fe; Carbon, C; Maganese, Mn.

Elongation: Generally taken as the percentage of stretch in a specimen two or eight inches long when the stress is the ultimate tensile stress.

Note: This forms a basis for comparing static ductility or toughness.

Latent Heat: The heat that produces change of state in a substance without raising its temperature.

Note: When a substance thus changed reverts to its original form this latent heat is given up.

Oxide: A substance combined with oxygen.

Example: Silicon dioxide, Si O_2 ; Manganese oxide, Mn O ; Iron oxide, FeO .

NOTE: Some oxides, such as the first, act as acids; others, such as the second, and third, act as bases. The first combines with the second or third, forming in the one case a silicate of manganese ($MnSiO_3$) and in the other ferrous silicate ($FeSiO_3$). Both these substances are components of the slag.

Oxidation: The chemical action, whereby oxygen is added to a substance.

Example: Carbon (C) + Oxygen (O) = Carbonic Oxide (CO).

Saturated Solution: A solution in which the solvent is holding all the solute that it can under the existing conditions.

Example: Molten steel containing about 2 per cent of carbon.

Slag: A molten mass of impurities formed in smelting or refining.

NOTE: In iron metallurgy the silicates of iron and manganese dissolve in each other forming part of the slag. This mass, in turn, dissolves other oxidized impurities.

Solution: A chemical union of two or more substances, some of which are dissolved in some of the others.

Example: Molten steel.

Solute: The substance dissolved by the solvent.

Example: The carbon of molten steel.

Solvent: The substance of the solution which does the dissolving.

Example: The iron of molten steel.

Reduction: The chemical action whereby substances are broken up into elements or other compounds.

Example: Silicon (Si) + Ferrous Oxide (2FeO) = Silicon dioxide (SiO_2) + Iron (Fe).

NOTE: Here ferrous oxide (FeO) is reduced and silicon (Si) is oxidized.

Reduction of Area: A phrase, representing the amount that the cross section of the specimen is reduced as compared with the original area; the measurement being taken at that point where the bar "necks" in breaking.

Note: This forms a basis for comparing static ductility or toughness.

Repeated Stress: A stress repeatedly applied and relieved with short intervals between applications.

Tensile Strength: The number of pounds per square inch of cross section necessary to pull the test specimen apart.

THE MANUFACTURE OF STEEL

The products of iron so blend with each other, that it becomes most difficult to differentiate between them and specifically state that at such a point wrought iron ceases to be wrought iron and becomes steel; or that at such a point steel ceases to be steel and becomes cast iron. Instead, it is much easier and more in keeping with practical nomenclature, to classify these substances according to the methods by which they are made. Thus steel is generally considered to be that product which is produced by the process of cementation, or the malleable compounds of iron made in the crucible, the converter, or the open hearth furnace. From a chemical standpoint wrought and cast iron are equally worthy of the name steel since all these products contain the same elements. If the elements such as silicon, manganese, sulphur, phosphorous, etc., are considered the impurities of iron, then wrought iron, containing less of these, would be a pure form of steel; and cast iron, containing more of them, would be an impure steel; while the products made by the methods enumerated above, would be those of steel lying between these two in purity.

Pig iron, or cast iron as it is sometimes called, is the product of the blast furnace. It is made by reducing the iron ore with fuel, which is ignited by a blast of air at high temperature. The fuel is usually coke; though sometimes charcoal or anthracite or a mixture of these fuels is used. Limestone is also charged with the ore and fuel to serve as a flux in the melting zone of the furnace. By dissolving what impurities are oxidized, and by mixing with the ash of the fuel and the gangue of the ore, a fusible slag is formed, which, being lighter than the molten iron, floats on top of it, and thus is readily withdrawn and disposed of separately. These three substances, namely ore, coke and limestone, are charged in alternate layers through a hopper at the top of the furnace, and mechanical means are now almost in entire use at the blast furnace works for this and other operations, because of the great size that they now build these furnaces, it being not uncommon to find them of a height of from ninety to a hundred feet. The air, of which some 25,000 cubic feet per minute is required for the larger furnaces, is blown first through large upright cylinders containing pre-

heated firebrick, which heats it, and then into the furnace through tubes called tuyeres, where it strikes the white hot coke at a point about ten feet above the level of the hearth, and oxidizes most of the carbon of the fuel forming carbonic oxide gas, which immediately rises, and passing up through the charge evolves different chemical reactions, until it with other gases formed pass off at the top of the furnace, thereafter to be used as fuel under boilers, or to be cleansed for use in the gas engines.

Thus the charge at the top becomes well heated, and as it gradually moves down through the furnace it gains in temperature, while chemical reaction becomes more energetic. Half way down the furnace, where the temperature is about 1470°F, the ore becomes reduced, and the iron formed drips down through the charge, absorbing carbon as it goes. It finally collects in a molten mass on the hearth, and is tapped or run from a hole near the bottom. The metal is run into sand moulds on the floor of the casting room, or into pig casting machines, where it soon solidifies. The fusible slag is tapped through a separate hole in the side of the furnace, run through a spout into cars and hauled to the slag dump. The oxidized substances pass into the slag, and the reduced substances pass into the iron on the hearth. It is for this reason that iron runs high in the reduced elements such as silicon, manganese, sulphur and phosphorous. This last element it is especially difficult to fuse into the slag, because the others are much more active chemically, and tend to displace it under the conditions that exist in the furnace. Thus low phosphorous ores are the ones most used, if a low content of this element is desired in the final product.

One of the oldest known processes for making steel is that in which the metal is melted and purified in a crucible. It is a method much in use to-day for our finer grades of tool steel. Small pieces of wrought iron, or wrought iron mixed with scrap, are put in graphite crucibles; and on top of this charge are placed charcoal, together with the other alloying elements desired, such as tungsten, manganese, etc., as well as ingredients to make the slag fluid. After sealing the crucible it is placed in a furnace heated to high temperature, and there left until the metal is "dead." This is the point at which the metal will pour without evolution of gases. The "deadening" is brought about by the absorption of silicon from the walls of the crucible, or from the cast iron, which is sometimes used in place of charcoal as a carburizer. This absorption of silicon deoxidizes the metal, and thereby strengthens it, but if too much is taken up it tends to weaken it. The steel, in this

process, gets its carbon, manganese, and silicon by absorption from the ingredients put on top, and though it is the intention to exclude the elements phosphorous and sulphur, yet these get into the finished material to small extent; the former from the slag in the wrought iron, and the latter from the walls of the crucible.

The next important process, and one named after its inventor, is the Bessemer. In this method a large vessel swung on trunnions is used, and into it is poured the molten metal, which may come direct from the blast furnace or a large receptacle known as a mixer. The process is then known as the direct process. Or the molten metal may come from a cupola. The process is then known as the indirect process. In either case the purification of this molten cast iron is accomplished by blowing air through holes in the bottom of the vessel and thence through the molten iron; thus oxidizing the impurities which in the form of a slag float on the surface. Silicon and manganese having the greatest affinity for oxygen under the prevailing conditions, are first burned out; and the combustion of these elements generates heat, and raises the temperature of the mass. Three or four minutes after the blast is turned on and carbon in its turn is oxidized. From now on, until the carbon is burnt out there will play from the mouth of the vessel, or converter as it is better known, a long flame called the carbon flame, which is, in reality, a flame of carbonic oxide gas. The drop of this flame at the end of nine or ten minutes is a sign, that the metal is decarburized to a percentage of not over .3 carbon. The converter is then turned down and the blast shut off. Phosphorous and sulphur are not eliminated in this process, because the compounds formed cannot be dissolved in the slag, owing to its greater attraction for the oxides of silicon and manganese, which it dissolves to the exclusion of the others. Hence the necessity of a pig iron low in phosphorous, if the same is to be used in the Bessemer converter.

After the blow, and while the converter is turned down, a sufficient amount of high manganese pig is thrown in for the purpose of giving the metal the proper amount of carbon, and, at the same time by means of the manganese, secure a more homogeneous metal, by deoxidizing the bath of any dissolved oxygen. It acts also as a desulphurizer, by forming a sulphide of manganese, which is soluble in the slag. The metal is then poured into a ladle, and from this it is poured into the iron moulds. The characteristics of the process are rapidity of action (10-18 minutes per blow), the melting of the metal in a receptacle other than the converter, the small charges handled (10-15 tons) and the heat imparted by the energetic combustion of the im-

purities. The above described process, which is common to America, is called the acid Bessemer process. Most operations are carried out in the large plants without recourse to manual labor.

Germany is the principal country to operate the Bessemer method with a view to the elimination of phosphorous. They accomplish this by charging into the converter sufficient limestone to give the resultant slag its basic tendency, thus enabling it to dissolve the phosphorous and also considerable sulphur as well. For this reason they are able to use a higher phosphorous iron in their work. It is necessary, in this process, to recarburize the metal after the same is poured from the converter, because the impurities and carbonic oxide formed, would tend to reduce the oxide of phosphorous that was in the slag, and thus rephosphorize the metal.

The next great process is the open hearth process; and it may, like the Bessemer, be classed either as acid or basic in its operation. The acid process is the least used of the two, but turns out a product generally agreed to be the better. The open hearth furnaces are large enclosed hearths, which are lined with refractory materials, and supplied with ports for the gas and air, which substances enter in a heated state, and unite, bringing about a temperature high enough to melt the iron placed on the hearth. Air is supplied in excess, so as to secure the oxidation of the impurities in the bath which, as the same is shallow, and agitated by boiling, is constantly causing the impurities to come into contact with the oxygen of the air at the surface of the metal. This process is a long one and six to ten hours are required for purification. The process would take a longer time if the air alone were relied upon as the oxidizing agent, so iron ore, which is rich in oxygen, is charged to hasten the action. In the acid method the hearth is lined with an acid material, and the charge is pig iron and scrap, this latter put in to reduce the carbon percentage of the mass. As in the Bessemer converter, silicon and manganese are the first elements to be burned out and these form a fluid slag, which floats on top of the metal and protects it from the intense heat of the flame. This slag is acid in its nature and will not hold a large amount of phosphorous or sulphur, and therefore when steel is made by this method, a pig iron low in these elements is a necessity. Tests are made, as the process proceeds, and when the carbon is oxidized the flame is shut off. Then the recarburizer is charged and the metal run into the moulds.

The basic open hearth process is the same as the acid, except that the lining is basic in character and a charge of limestone is used to make the slag so basic in quality, that it will

hold the oxidized phosphorous. The rebarburizer is put in after the metal is poured, for the same reasons as stated under the basic Bessemer process.

The chief characteristics of the open hearth process are the long time for purification (six to ten hours), and the large amount handled (thirty to seventy tons). It gives a better metal than the converter process, due probably to the long time taken and the large percentage of scrap used.

THE CONSTITUTION OF STEEL

A study of the constitution of steel is perhaps best preceded by a short review of the nature of solutions, in order to better understand the changes that take place, as steel cools from its high temperature down to that of the atmosphere.

When a liquid dissolves a substance we have a solution. The substance dissolved is called the solute, and the dissolving substance the solvent. Some substances will dissolve in all proportions; others only in certain proportions. In the latter case the solution is said to be a saturated one when the solvent is holding all the solute that it can. If more than this amount be added the solute will precipitate, since the solution is already saturated. As a rule an increase in the temperature will cause an increase in the dissolving power of the solvent; and hence at a higher temperature the precipitate will disappear in solution. Gold and silver are examples of substances that dissolve in each other in all proportions, whether liquid or solid. When a liquid solution of either one in the other freezes or solidifies, both substances will freeze out together in the same crystal. When substances freeze in this manner the resulting solid mass is also a solution of the one element in the other, only in this case it is a solid solution and not a liquid one, since the crystals of one are dissolved in those of the other.

Tin and lead are examples of two elements which when liquid may be in solution in any ratio, but since they cannot dissolve each other when solid, we have when the mass is frozen, not a solid solution, but an intimate mixture of crystals of lead and tin. The solidification, in this case, takes place as a saturated solution. The solution cools and reaches a temperature at which the solvent is saturated with the solute. Further cooling makes the mass supersaturated, and the substance in excess precipitates, while at each degree drop in the temperature the precipitated solid mass increases, thus in turn enriching the liquid mass remaining, in its percentage of the solute. After a certain temperature is reached, this liquid remaining,

called the mother liquid, will have attained certain proportions of the solute; and further drop in the temperature will not cause any more freezing of the excess metal alone. Instead, at this point, the solution will solidify in intimately mixed crystals of lead and tin, and not in solid solution as occurred with the gold-silver alloy. The latent heat given up at this time is enough to seriously check the drop in temperature of the mass, and until this last alloy is frozen, the temperature is almost stationary. This last freezing alloy of elements in such proportion that both solidify together, is called the eutectic, which means "well melting" solution, or the solution with lowest melting or freezing temperature.

Now consider steel as composed of its two most abundant elements, namely iron and carbon, and we get on solidification (if the carbon does not exceed 2.2 per cent) a solid solution, or a solid formed in a manner similar to the alloys of the gold-silver series. In this case the two crystallizing substances are iron and probably cementite (often called iron carbide), since this is the form in which carbon seems to exist when in iron. It is a compound of one atom of carbon with three atoms of iron, thus taking the chemical symbol Fe_3C , and it is very hard ($H=6$). There is some doubt as to whether when the mass is molten, the carbon exists in this form; but from what occurs later it would appear as if this was the condition when the mass had solidified. Therefore, we may again state, that the solid solution will consist of crystals of iron and crystals of cementite dissolved in each other; and this will occur for all proportions of carbon up to 2.2 per cent. These amounts of carbon cover all grades of steel; so we may say that all steel freezes in solid solution. This solid solution has been independently named austenite, and as it cools a strange change takes place. We find that the solid solution does not survive to ordinary temperature, but when a certain temperature is reached, precipitation takes place according to the laws of the lead-tin series, the only difference being that in this case, they take place within the solid mass instead of from a liquid condition. If the steel be hypoeutectoid, that is have less than 0.9% carbon in solution, then the iron of the austenite will separate out first, because it will be in excess as certain temperatures are reached, and in this state it is practically pure, and is called ferrite. In other words the austenite has become supersaturated with ferrite with decline in the temperature, and as it cannot remain in solution, it of necessity precipitates. This precipitation, as with the lead-tin alloys, causes an enrichment of the remaining austenite in the other component cementite, so as to soon bring about a 0.9% carbon ratio of the remaining solid solution.

Beyond this the ratio cannot increase, and the remaining austenite is now precipitated into narrow layers of ferrite mingled with layers of cementite. This final conglomerate is called pearlite, from its "mother of pearl" appearance, and the layers are not much more than $\frac{1}{40,000}$ of an inch in width, so that it takes microscopes of high power to bring it out. This substance, pearlite, or solid solution alloy of lowest transformation point, is called the eutectoid; and it is a conglomerate formed within the solid metal in the same manner as the eutectic is formed from the liquid solution. Likewise had the steel been of just 0.9% carbon composition to start with there would have been no excess substance at all, and the entire mass of austenite would be transformed into pearlite when the transforming point was reached. The temperature for this eutectoid formation is about 1290°F., and so from the above discussion we see that all steel cooled slowly past this point must finally consist of either ferrite or cementite mixed with pearlite, or of pearlite alone. The ratio of cementite to ferrite in this eutectoid pearlite is approximately 1 to 6.4. The pearlite can be calculated for any steel as follows:—

WHEN CARBON IS 0.9% OR LESS

$$\begin{aligned} \% \text{ C} \times 15 &= A = \% \text{ cementite which exists in the pearlite} \\ A \times 6.4 &= B = \% \text{ ferrite that exists in the pearlite} \\ A + B &= C = \% \text{ of pearlite in the mass} \\ 100 - C &= \text{Excess of ferrite in the mass.} \end{aligned}$$

WHEN CARBON IS OVER 0.9%

$$\begin{aligned} \% \text{ C} \times 15 &= A = \% \text{ cementite in the mass.} \\ 100 - A &= B = \% \text{ ferrite in the mass.} \\ \frac{B}{6.4} &= C = \% \text{ cementite in form of pearlite.} \\ A - C &= D = \text{Excess of cementite in the mass.} \\ 100 - D &= \% \text{ of pearlite in the mass.} \end{aligned}$$

The ferrite formed in slow cooling steels is very pure iron; ductile, magnetic, of about 45,000 lbs. tensile strength and is called alpha ferrite. This is to distinguish it from the forms in which it exists when above the saturation temperatures. Above these points the ferrite is chemically the same as below, but has assumed a different allotropic condition, so that when in the solid solution state of austenite it is known as gamma ferrite; and it is much harder than the alpha ferrite, and non-magnetic, besides. Likewise between these two forms there comes into existence a third, called beta ferrite, which is very hard and but

slightly magnetic. In low carbon steels, say under 0.3%, it is possible to distinguish these three states or allotropic changes in the ferrite, but as carbon increases beyond this point they run closer together, until the points of transformation appear as one. It is customary to call these points of transformation the critical points, and when they occur in the process of cooling, they are further called the points of recalescence. It should again be remembered, that at these points no chemical changes in the ferrite occur, but only allotropic modifications, and that these take place in the ferrite whether it is combined with the carbon forming cementite, or whether it is separate as excess ferrite. The cementite, when composed of gamma or beta ferrite, is much harder than when composed of alpha ferrite, and it is less magnetic. From the above I think it can be now seen, that as the solid solution austenite (cementite of gamma ferrite and a separate mass of gamma ferrite dissolved in each other) cools, there must be at different stages through the transformation range masses of crystals more or less fully developed towards the final structure, which would be that of the eutectoid pearlite.

These various conditions have been named, and though their compositions are not fully known yet many of their physical characteristics are; and it is now agreed that they occur in the following succession, namely: austenite, martensite, troostite, osmondite, sorbite, and pearlite. Now as the critical points of steel are reversible upon reheating, that is to say, since we can by heating a cold piece of stock up to about these points, obliterate the pearlite or normal structure and cause the cementite and ferrite to pass from alpha form back into solution in the gamma form, it is evident that by quenching steel from different points within the transformation range we should be able to retain some one of the above forms in the cold. The most practical method, however, is to cool from above the last critical point and obtain the different forms either by altering the rate of cooling or by subsequent tempering. It is evident, now, that the explanation of the hardening of steel by quenching is in the retention of some one of these hard forms, which in turn is due to the fact, that a certain amount of time is required if each of the transitions is to take place, and the quick cooling due to quenching prevents or obstructs the change. For example, assume the steel quenched. Then as the temperature passes the critical point in cooling, the desire of the structure to reach its normal state steadily increases; but its attainment is offset by the steadily increasing molecular resistance, due to the chilling of the plastic mass. On the other hand, the explanation of softening by annealing, or slow cooling, is that plenty of time has

been allowed for complete change from the harder forms of gamma or beta ferrite to the softest variety, namely alpha ferrite. It may thus be readily seen, from what has gone before, that the hardness and brittleness of steel increase with the rapidity of cooling below the critical range. The idea that steel can be made harder by heating it to temperatures well above the critical range is a fallacy, because once the cementite and ferrite are transformed from their normal state into the solid solution form of austenite, further application of heat is useless. The reason for the higher hardening power of high over low carbon steels is due, not to the carbon itself, but to the form in which the iron or ferrite exists. It seems as if carbon brought about a brake action effect upon the tendency to change from austenite to pearlite; and the higher the carbon the more the brake power exerted and consequently the harder the steel. Increased carbon means more cementite in the mass, and though a quantity of this substance in itself may make steel hard, yet it exerts, because of its carbon, a greater effect, by promoting the brake action on the change of the austenite into the more normal forms of ferrite and cementite.

Since the bulk of hardening steels consist in their normal state mostly of pearlite, it becomes of great importance to be sure of our determination of the points of recalescence, and to assure ourself in regard to the reversibility on reheating. As before stated, a temperature of about 1290°F seems to be the point of commencement of change of state from austenite into pearlite. Probably this temperature is a little below the true point of transformation, because of the natural inertia to change of form, and perhaps because of some phenomena akin to surfusion. At all events, it is found that in practice, when we heat steel before quenching, it is necessary to go to a temperature some 80° F to 100° F higher; this difference probably being due in its turn, to the natural inertia to change from the form of pearlite into that of austenite. Since these points on reheating are different from those of cooling they go under the name of the points of decalescence. It is a fact, however, that we could bring the change about by heating to 1290° F or slightly higher, but only by allowing the steel to stand at this temperature for a considerable number of minutes. To hasten the change it is necessary to heat, as stated above, to a temperature 80° or 100° F higher, which would mean a working temperature of about 1370° F to 1390° F . In practice, temperatures of from 1400° F to 1600° F are often used, but as previously stated, when once the transformation has taken place further rise in temperature is useless, and besides only tends to deteriorate the structure, as will later be shown, by

making it coarser; and there are good grounds for believing that a structure like this makes the steel less difficult to penetrate, or in other words, makes it less hard. All grades of steel will harden to some extent, though not until we get above .3% C composition will it be very noticeable. A 0.4% carbon steel will harden so as to cut soft iron and hold an edge, but most tools of ordinary carbon steel run 1.0% carbon and more. Sudden cooling to below 200° F is necessary if the steel is to be very hard. Any check in the rate of cooling will result in temper drawing, and hence change to one of the lower transition structures. This is the reason for a less hard steel when oil is used as the quenching medium. It is equivalent to hardening in water, and drawing the temper. An equal degree of hardness will best be formed by an even and uniform heat, and it is necessary, if we wish to escape strains of an uneven character, and consequent shrinkage cracks. A bath of even temperature, high specific heat, viscosity, and conductivity is essential, if we would have the greatest chilling effect. Agitation of the quenching medium is also effective, in that it serves to brush off particles of steam or gas that may collect on the parts, such gases being detrimental, inasmuch as they are poor heat conductors. Hardening increases the tensile strength and the elastic limit of the steel; but greatly reduces its ductility and ability to withstand sudden shock. In order to partly restore this latter characteristic, tempering is resorted to which consists of a reheating of the hardened product to temperatures, as a rule, between 400° F and 600° F. The theory of tempering is that hardened steel at atmospheric temperature is under a natural strain, the tendency of which is to cause the structure to revert to its normal condition as soon as conditions are made under which it may exert this desire. A slight reheating favors the change and allows of a transformation of some of the molecules to their normal condition, thus increasing the ductility of the mass, and at the same time decreasing the hardness. After heating to temper, it is immaterial whether we cool quickly or slowly since the degree of temper is not altered.

With ordinary carbon steels it is difficult to harden the metal so that austenite will be retained in the cold. In fact we cannot obtain it pure, since there is always time, no matter how sudden the chilling, for partial transition to take place. Some may be obtained if a steel high in carbon is quenched from a high heat; but it is very unstable at ordinary temperature and is readily changed to the next form, martensite, upon application of heat. As before stated it is the solid solution of cementite in gamma ferrite. Above the critical range all steels are in this form, and only at temperatures above this is

it stable. Elements such as manganese and nickel seem to aid the carbon in retaining steel in this form.

Martensite is the next transition form and it is the usual constituent of hardened carbon steels. It is a form more stable than austenite and considerably harder, probably consisting of a mixture of cementite in gamma, beta and alpha iron; obtaining without doubt, its magnetic properties from the alpha iron in the mass. The application of heat changes it to the next forms, first of which is troostite; and so we find this form in all tempered steels. Troostite is formed by quenching from within the critical range of temperatures, or by quenching from above that range in hot water. It is found in the central parts of large hardened pieces, due to the slow cooling actions inside of them. It is softer than martensite, but probably like it consists of cementite in gamma, beta, and alpha ferrite, but with a much greater proportion of alpha ferrite.

Osmondite is the next form and one but recently discovered. It is principally a solution of cementite in alpha ferrite.

After osmondite the next form to appear is sorbite. It seems to be a form very close to pearlite, but with crystals of cementite and ferrite imperfectly formed. It can be obtained by quenching from temperatures near the lower end of the critical range, or by chilling in oil. A temper of about 600° F seems also to form it. It makes a very tough structure and is softer than any of the above forms.

Pearlite, the normal and next form, is, as previously stated, a mixture of layers or crystals of cementite and alpha ferrite. Its composition is 0.9% carbon and it is formed in all steels by slow cooling, being either alone as in a steel of 0.9% carbon, or mixed with an excess of ferrite or cementite depending upon whether the metal was hypo- or hyper-eutectoid in its composition, that is as to whether it contained less or more than a 0.9% carbon. The tensile strength of steel is greatest when about of this proportion.

Alpha ferrite, as found in annealed steel, is almost pure iron, and is very magnetic. It carries in solution and combination small amounts of the elements silicon, manganese and phosphorous that are found in steel. It is soft, very ductile and is the chief constituent of low carbon steel. Wrought iron is the nearest commercial product like it. Very slow cooling through the critical range is necessary for its complete formation; though a quick and quite satisfactory method is to heat to a point just below the range and then suddenly cool by quenching. This process is called water annealing.

The elements silicon, manganese, sulphur, phosphorous, oxygen and possibly nitrogen are present in all steels to a more

or less degree. The first combines with iron to form possibly a series of silicides, most important of which is the one of symbol FeSi. Silicon up to a percentage of 0.6 is not considered, as a rule, to be harmful in its effect on soft steels. Silicon is sometimes used as a deoxidizer because of its great affinity for free oxygen; but it usually gets into the metal from the pig iron used for making the steel.

Manganese, like silicon, is a great purifier, in that it deoxidizes the bath. It is for this reason that a recarburizer high in this element is used. If its percentage does not exceed 1.0 it is generally believed to confer no bad properties upon soft metals; in fact it increases the tensile strength of steel as it increases beyond 0.4%. It seems first to combine with all the sulphur it can take up forming the compound manganese sulphide (MnS). This sulphide occurs in drops, and upon rolling, the tendency is for these to spread out into thread form, or "ghost lines," as they are called in the mills. It weakens the steel; but, though a brittle form, it is very advantageous to have as much as possible in this condition; and hence there should be manganese enough to secure all the sulphur. Though a little less than twice as much would be the theoretical amount, yet it is found that when its amount is at least four times the sulphur content the combination is easier effected. Part of the manganese combines with carbon to form a hard carbide (Mn_3C) which is often found mixed with cementite, both being at times, in the same crystal. Manganese tends to make the grain finer, thus offsetting the coarsening action of phosphorous. Manganese seems to have a tendency to cause steel to crack upon quenching.

Sulphur, as stated above, will all combine with manganese if there is sufficient of the latter present. What does not occur in this form will combine with iron to form iron sulphide (FeS). In this state it will make the steel more brittle than in the form of manganese sulphide, for whereas manganese sulphide distributes itself throughout the mass in the form of drops, the iron sulphide, on the other hand, will be found developed in sheet form, which naturally is more weakening to the structure since it prevents close adhesion of the crystals. Besides, at rolling or forging temperatures, both forms of sulphide are fluid, and this is injurious, inasmuch as it causes cracks to develop. This explains the so-called "red shortness" of steel of high sulphur content.

Most injurious of all elements known is phosphorous, since it makes steel brittle and renders it unable to withstand shock or hard service. It dissolves in the iron, and as solidification of the steel proceeds, it separates as a eutectic of such

a low freezing temperature, that it is fluid after the great bulk of the metal has solidified. This allows the eutectic to flow around the formed crystals and thus make a brittle network. Its effect is less severe in low carbon steel, because with ferrite in such excess there is less of the eutectic formed. For these reasons it is always well to keep the content of phosphorous low in all steels, especially those of high carbon content. Its tendency is to make the structure of the steel more coarse.

Oxygen forms oxides which are harmful to either soft or hard steels, these compounds acting much the same as sulphur. Bessemer steels are apt to contain more of these compounds than those made by other methods.

The more evenly distributed are the above impurities the better will be the finished steel, but as is well known to the steel maker, they tend to collect or segregate. The cause of this action is that when the steel, which has been poured into the moulds, commences to solidify, these elements, or their compounds, which at the high temperature of the molten metal are in solution, are in turn rejected from the freezing crystals of austenite. In other words the crystals become supersaturated with them upon freezing, and throw off the excess which are at once immediately redissolved in the remaining hot liquid mass within the outer frozen walls, thus at the same time enriching it in these impurities. This process continues until that part of the ingot to last freeze, will, as a rule, be found richest in these elements, and this point is usually in the inner upper third of the ingot. At this same point is formed a pipe or cavity due to the continual shrinkage away from the last frozen mass of the exterior walls, which are freezing ahead of it. The pipe may be lessened by slow pouring, or by stirring of the top of the ingot so the same cannot freeze over. Segregation is lessened by the use of small ingots, which promote quick cooling of the mass. It is usual for this top third of the ingot to be sheared off and scraped so that this segregated portion can be kept out of the finished product. Aluminum seems to offset segregation by causing less agitation from escaping gases; for if agitation occurs the crystals that are forming out into the molten interior or open sea, as it is sometimes called, are not so apt to embrace the impure elements that are being rejected, and hence they become redissolved in the molten interior. Gases in solution, as well as the other elements noted, are also rejected as the crystals freeze; and if they get caught in the crystals the result is a blow hole in the steel, which may be minute or comparatively large. If the blow holes are well inside, the mechanical work done on the ingot will close them up, and the resultant bad effects, which

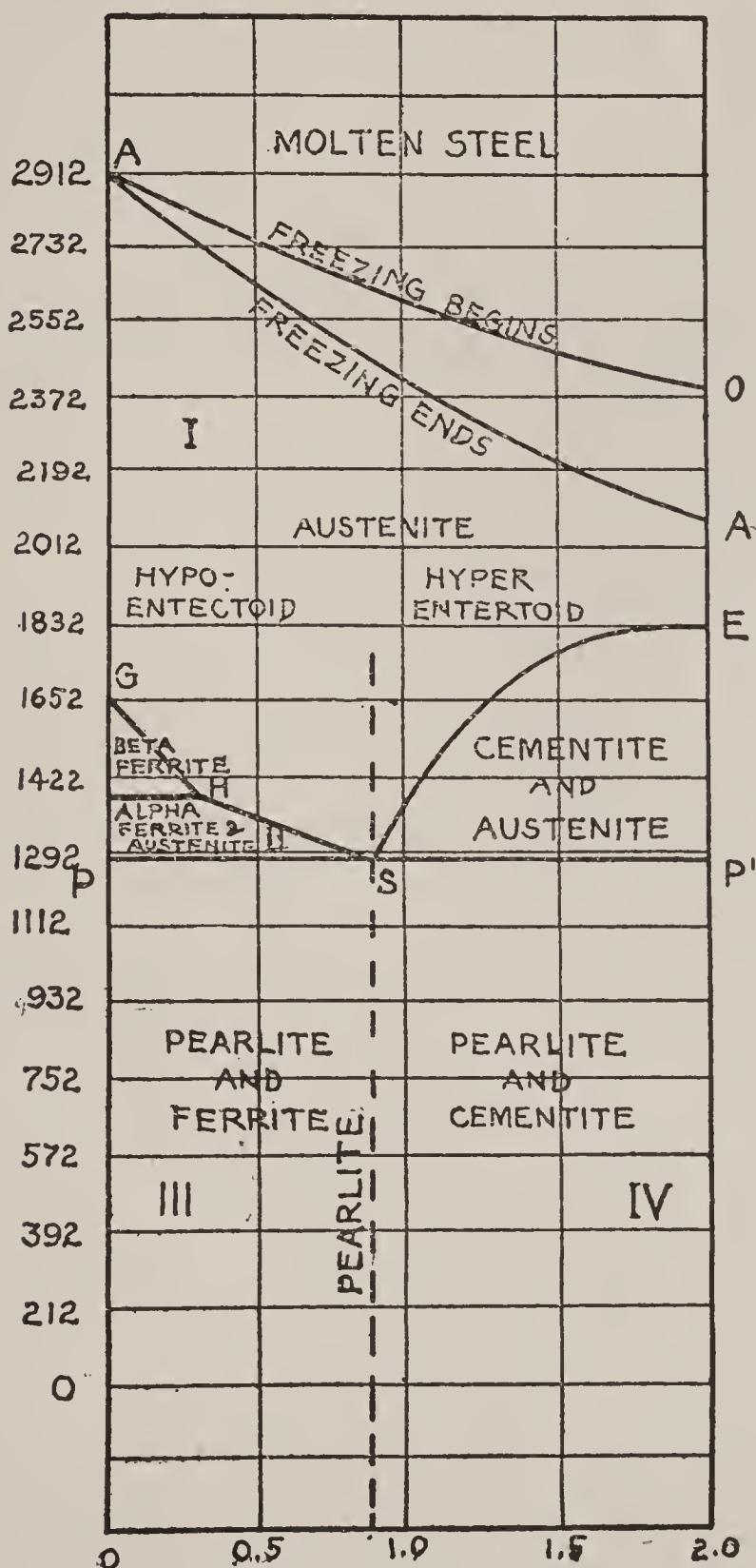
otherwise would appear, will be well eliminated; but if they are near the edge their walls become oxidized on exposure to the air, and they then do not easily weld together. The blow holes seem to be deep seated as the percentage of manganese plus 5.2 times the percentage of silicon decreases from 1.66. One possible cause of the gases is the reducing action of carbon in the recarburizer upon the oxides of iron which are always present, the resultant gas being carbonic oxide. The use of elements such as silicon, manganese, aluminum, vanadium, etc., are often resorted to in order to purify the metal of the dissolved gases.

We will now consider heat treatment as it effects the size of the grain, and reference will be made to the freezing curves of steel. Chart I is that part of the Roberts-Austin diagram which pertains to steel, it being carried further to the right in the original to cover irons of higher carbon percentage, namely cast irons. It ends here, at the two per cent point, which is about the steel limit. The line A o gives the temperatures at the commencement of freezing of the molten steel and the line A a gives the temperatures at the end of this action. From here down to the line G H S E the steel is in the condition of austenite, or a solid solution of cementite in gamma ferrite. G H S represents the temperatures for steel under 0.9% carbon, at which the excess substance, ferrite, commences to precipitate, as before explained, changing first into beta and finally into alpha ferrite. The chart shows that to the left of point H, which represents a carbon steel of about 0.3%, the critical points designating change of form from gamma into beta and then alpha iron are discernable; but to the right of this point the upper critical point has so run into the second that they appear as one in the line H S E. The third critical point is that of separation of the eutectoid, namely the temperature as shown by point S.

The figure shows also that while the temperatures for the formation of ferrite (G H S) or cementite (S E) vary with different grades of steel, yet for all of them the temperature at which the eutectoid forms in the same, namely S.

Region III, on the chart, is that of pearlite and alpha ferrite, this domain being to the left of the 0.9% carbon point; while region IV is that of pearlite and cementite, this domain being to the right of the above mentioned point. A steel of exactly 0.9% carbon, consists of pearlite alone, when in the normal state. It should be stated that since the chart represents the freezing points, it is necessary on reheating to heat to points about 80° F to 100° F higher in order to reverse the processes, this being caused by molecular inertia, as previously explained.

PLATE I



ROBERTS AUSTIN DIAGRAM

At the temperature of point S we get the finest grain in most steels. At each degree rise in temperature above this point the grain size will increase almost exactly in proportion to the increase of temperature. This sadly weakens the steel, especially those of high carbon, both strength and ductility decreasing; but in low carbon stock this latter quality is not altered so much. To whatever temperature above S the steel is heated we will bring down from that point the grain size of that temperature, and it can only be gotten rid of by special heat or mechanical treatment. This increase in grain size is often not noticeable to the eye, but nevertheless it is there if we have heated our stock above the point S. In order to eliminate this grain size, we can reheat the stock again to temperature S, and all the pearlite will go into solid solution in the finest grain form. Heating to any point short of this is ineffective, and our original grain size is not altered; while heating beyond point S immediately results in the steady enlargement of the newly formed fine grain of the solid solution which forms at this point. We should reheat low carbon steels to a point higher than temperature S, because, though as stated above, this is the point for a new crystallization of the pearlite which is forced into solid solution, yet, on the other hand, there will be a considerable quantity of free ferrite, which substance will not attain its finest grain until it in its turn is forced into the solid solution. The temperatures for this change are those at which it separated out as the excess substance on freezing, or the temperatures of the line G H S. In other words only the eutectoid will go into solution at the point S; and we must heat higher to return the excess substance, ferrite. Of course, in heating above the point S, the newly formed fine grain of the solid solution will at once commence to increase, so that while we are trying to refine the ferrite by further heating, on the other hand we are destroying the newly crystallized grain size of the solid solution; but since the ferrite is so large in amount (in steel under 0.5% carbon it is in excess), it is deemed advisable to follow this method. The above explanation is an answer as to why a steel of this composition cannot be finely refined.

Theoretically we ought to secure the metal of best grain by heating to S a steel of the eutectoid ratio, namely 0.9% carbon, because when this temperature is reached the entire mass will go into solid solution, and further heating will be unnecessary. This is, perhaps, a cause of the great strength shown by eutectoid steel when properly heat treated.

With steels over 0.9% carbon it would be necessary to reheat to the line S E if we were to force into solid solution the

excess substance of cementite and thus refine that portion, but since in steels of this composition the pearlite is so much the greater in amount, it is better to reheat only to temperature S, and thus not cause a re-enlargement of this finely formed grain, for the sake of refining the small excess of cementite that might be in the mass. In hypo-eutectoid steels these grains are surrounded by ferrite, and in hyper-eutectoid steels by the excess substance cementite. The number of grains to the square inch in well refined steels of fair carbon percentage may be as much as ten thousand or more.

The other method of refining the grain, though not so effective as the heat treatment method and not always applicable, is to break down the grain size by mechanical work. This is the only method known which can be used in the making of large pieces, and it is for this reason that great care is taken in the rolling and forging of the same. A high temperature is necessary if the ingot is to make many passes through the rolls, and certainly one higher than that of finest crystallization, namely S. Consequently when the rolling commences, we have in the mass a coarse crystallization. Constant work upon the part will break down this grain; and if we continue rolling or forging until temperature S is reached, we will have attained the finest grain size that can be got by mechanical working. If we stop at any point above S, the grain size of that temperature at once forms and will come down in the part if no more work is done. Therefore mechanical work should be continued until the line G H S P' is reached; but when carried beyond these temperatures strains will be set up in the part. All large pieces show different grain size because the centre must be always hotter than the surface layers; and for this reason it is considered good practice in the mills, to roll the shapes at the proper temperature when the greatest amount of work is being done. A welded piece is often stronger in the weld because it is at this place where the greatest amount of work and consequent reduction of grain has occurred; while in sections upon either side the coarse grain of the high welding temperature is to be found. Hence it is weaker here and more apt to break at these points. Therefore all welded parts should be given heat treatment, as above described.

In practice we often heat treat by heating to the line G H S P' and then after quenching draw the temper. Quenching from these points refine and harden the stock, and it is to relieve it of all hardening strains that the temper is drawn to high points. This changes all austenite into the lower forms of sorbite or pearlite, and we consequently obtain the strongest metal consistent with good ductility.

It can now safely be stated that crystallization of steel through service cannot take place. Heat is the necessary adjunct for crystallization. The common belief that crystallization will occur through continuous work is a fallacy. To be sure we see in certain fractures a coarse grain, but all evidence tends to prove that it must have been there in the beginning. There are, in fact, good grounds for believing that constant straining of large crystals would, in time, pull them out into a fibrous form.

In annealing we should heat to the line G H S E to secure complete transformation into austenite and then cool very slowly in order to transform this substance into pearlite and its excess member; but if we wish to attain the best grain size with softest condition, we should double anneal the stock by first heating to the line, as stated above, and then give the part a second reheating to the line G H S P' to obtain the best grain. Besides its softening effect, annealing is a factor in removing strains caused by uneven cooling among the different crystals.

Burnt steel cannot be refined; but burning takes place only at temperatures much higher than is ordinarily used in practice. The crystals here seem to be forced apart, which possibly may be caused by the formation of gases either by chemical action or by their being thrown out of solution by the high temperature. Mechanical work may, to some extent, better such steel by closing up the grains, but for most purposes such stock is worthless.

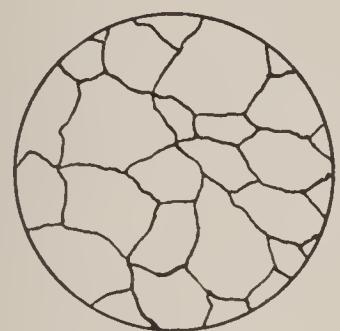
The cuts on plate II may now be of assistance in explaining this discussion of grain size and structure.

Figure 1 may be assumed to represent the magnified condition of a piece of stock heated to a temperature well up in region I. The network defines the grain size and conveys to us the idea of the space that exists between the crystals. The condition of the grain or crystals is that of austenite, or the solid solution of cementite and gamma ferrite.

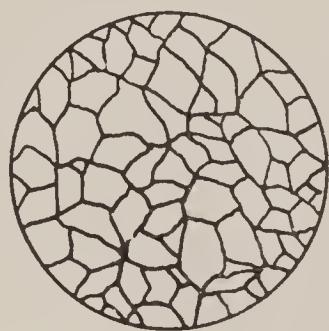
Figure 2 represents the above piece of steel after the temperature has slowly dropped down to that of region II. The increased heaviness of the network indicates that the spaces between the crystals have been somewhat filled with ferrite, (if carbon is less than 0.9%), or cementite (if carbon is more than 0.9%) which must precipitate from the austenite as soon as temperatures of the line G H S E are attained.

The iron or ferrite at this time is of alpha modification, it having probably passed through the beta stage in reaching this condition. The grains themselves, are still austenite in character.

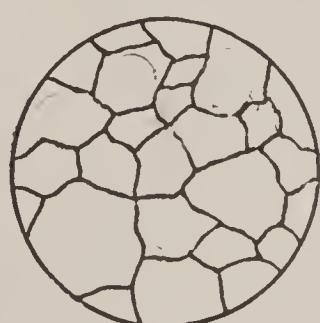
PLATE II



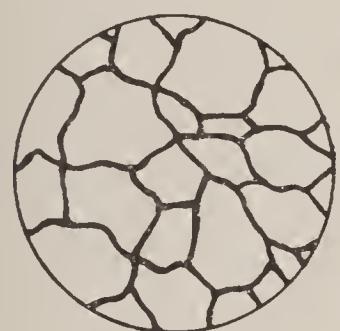
1



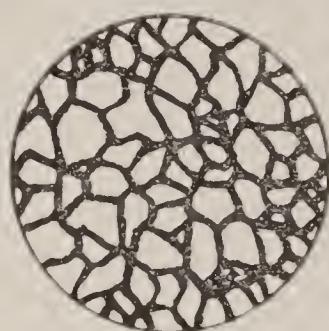
4



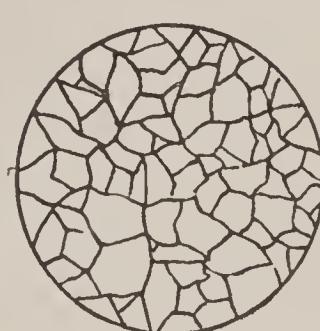
7



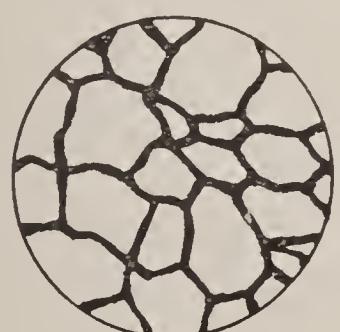
2



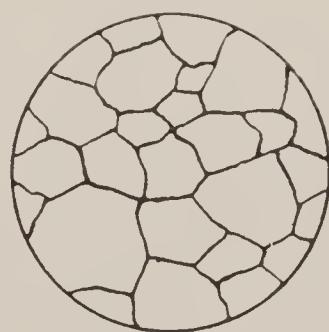
5



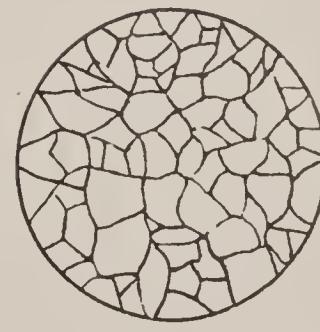
8



3



6



9

Figure 3 represents conditions after the temperature has past the line PSP'. The network has now attained its maximum thickness of ferrite, or cementite, as the case may be, and the constitution of the enclosed grains is pearlite, the transformation from austenite having occurred as the temperature passed the point S.

Figure 4 shows the structure after this same piece is reheated to the line G H S E and subsequently quenched. Let us state that when temperature S was reached, the coarse grains of pearlite were suddenly changed into austenite in the finest grain size. In other words the steel had been refined. Further heating across the critical range resulted in a gradual weakening of the old network, as the substance of which it was composed became redissolved by the austenite meshes. While this original coarse network was being obliterated, the newly formed fine grain within it was gradually becoming more coarse, because the temperature was rising above that of point S, the point of finest grain formation. Therefore our figure shows a refined structure with the old grain obliterated, yet a structure somewhat coarser than it otherwise would have been had we not sought to rid it of the above mentioned network. The constitution of the mass would be entirely austenite to the solid solution of cementite in gamma ferrite if the cooling were instantaneous, but because this is not the case the form assumed will be one lying between that of austemite and pearlite, this depending upon a variety of conditions, as was previously shown.

Figure 5 shows the structure of this same piece after it has been annealed from the line G H S E. Note the network of the excess substance due to prolonged cooling through the critical range. Note also the refined grain and the entire obliteration of the old grain size. The constitution of the network may be either ferrite or cementite, and the grains are pearlite.

Figure 6 represents a steel of eutectoid proportions, namely 0.9% carbon, after heating to a temperature high in region I. The grain size is large as was the case with Figure 1. The constitution is in the form of austenite.

Figure 7 shows the same piece of 0.9% carbon steel after it has slowly cooled below the temperature of point S. Note that here there is no precipitation into the network since neither ferrite or cementite are in excess. The constitution of the mass is entirely pearlite. Note that the grain size of the high temperature is retained in this piece.

Figure 8 represents the same piece reheated to the point S and subsequently quenched. Note the refinement of the grain which should be the best of any steel since stock of this composition all goes into solid solution when temperature S is reached.

The constitution will be of a form lying between austenite and pearlite.

Figure 9 shows the result when this same piece is reheated to line PSP' and very slowly cooled or annealed. Note the refined grain as compared to that of Figure 7. The constitution of the mass is that of pearlite entirely, there being no substance in excess to precipitate upon cooling.

Regarding the physical tests to which steel is usually put we may mention those of ultimate tensile strength, elastic limit for tension, ductility, and the tests for resistance to "fatigue." Less frequently tests are made for compressive strength, torsional strength and degree of hardness. These properties will vary greatly depending, as before stated, upon the condition of the structure, chemical constitution and kind of mechanical treatment. With ordinary steel whatever tends to increase the ultimate strength decreases the ductility or toughness. Thus, hardening, and mechanical working increase the ultimate strength and reduce the ductility, whereas annealing increases the ductility but decreases the strength. It is impossible to get maximum strength and ductility at the same time.

Carbon is the great strengthener of ordinary carbon steel, and more strength is gained by its use with less loss of ductility than by any of the other elements. The strength increases in proportion to increase in carbon until about 1% is reached, after which there is a decrease. Thus if one specifies high strength they should not set a limit on the amount of carbon, since it is the best ingredient by means of which high strength can be attained.

If silicon does not exceed 0.6% in soft steel its effect on the strength is slight, and no bad qualities are conferred on the metal.

Manganese adds to the strength after amounts of 0.3 to 0.4% are attained, and its effect increases as the carbon increases. Enough should be present to counteract the "hot-shortness" or liability of cracking when rolled that the element sulphur seems to cause. Manganese and silicon are kept lower in tool steels, say 0.4 and 0.2% respectively.

Sulphur does not appreciably effect the ultimate strength or other properties of cold steel. The amount should be always low to avoid "hot-shortness."

Phosphorous increases the ultimate strength, but because of its deteriorating influence thanks to its making the metal "cold-short" or brittle, it should always be as low as possible. In tool steels this element and sulphur should be very low, say 0.02 and 0.04% respectively.

After a study of the records of hundreds of tests on acid

and basic open hearth steel, Campbell evolved a set of formulae for the ultimate tensile strength of this kind of steel. He checked many future heats with them, and its accuracy was proven within fair limits. The influence of silicon and sulphur is neglected, and only that of carbon, manganese and phosphorous taken into account. The variable R is added to cover variations in strength due to different conditions other than those of a chemical nature. R becomes a + quantity where the part is small in section or the temperature conditions low during rolling. If the temperature conditions are high during rolling or if the part is large in section R becomes a — quantity. The formulae follow:

$$\begin{array}{ll} \text{Acid Steel Ult. tensile strength} = 40000 + 1000 C + 1000 P + X \text{ Mn} + R \\ \text{Basic Steel} \quad " \quad " \quad " \quad " = 41500 + 770 C + 1000 P + Y \text{ Mn} + R \end{array}$$

The unit for carbon is 0.01
 " " phosphorous is 0.01
 " " manganese " 0.01
 " values for X and Y follow:

PER CENT CARBON	ACID STEEL X	BASIC STEEL Y
0.05	110
0.10	80	130
0.15	120	150
0.20	160	170
0.25	200	190
0.30	240	210
0.35	280	230
0.40	320	250
0.45	360	
0.50	400	
0.55	440	
0.60	480	

The values X begin when manganese content = 0.04
 " " Y " " " " " = 0.03

Thus if an acid steel analysis was as follows:

$$C = 0.16 \quad Si = .033 \quad Mn. = 0.40 \quad S = 0.45 \quad P = .060$$

Then the tensile strength would be

$$40000 + (1000) (16) + (1000) (6) + (120) (40) + R = 65800 + R \text{ lbs. in which case R may be } + \text{ or } - \text{ as mentioned above.}$$

The ultimate strength as derived from physical tests of standard specimens is, of course, not used in the calculations of structures, until the amount has been divided by a proper factor of safety, to allow for the effect of variation in shape of the part and other inconsistencies due to the different local conditions that are bound to exist in each separate case.

The elastic limit is about two-thirds the value of the ultimate strength if the steel be mild. As the steel becomes harder this ratio is less.

The elongation in mild steel will vary between 25 and 30% in a length of 8". As steel becomes harder this is greatly lessened.

When a structure is subjected to repeated or alternate stress, the breaking load is much under the ultimate tensile strength of the material.

Factors of safety for static loads run from three to four, and for live loads from six to eight.

Turner states that since the elastic limit, reduction of area and dynamic alternations that a specimen will test out to represents the useful strength, static ductility and "fatigue" resisting properties respectively, it is possible to embody all three in an expression such that when these three characteristics of the steel are known there will be a proper basis on which to make comparisons. He divides the product of the elastic limit, reduction of area and dynamic alternations by 1,000,000 to obtain what he calls the "quality figure." Thus if E represents the elastic limit, R the reduction of area and A the dynamic alternations, then the "quality figure" F is expressed as follows:

$$F = \frac{E \times R \times A}{1,000,000}$$

ALLOY STEEL

The desire within recent years to increase the ultimate strength, elastic limit and hardness of steel without destroying its ductility or toughness, has lead to the development of a class of steels popularly called alloy steels. It was found by inducing certain elements, either singly or together, in various proportions into steel of ordinary constitution, that many remarkable qualities were attained. The final results cannot always be predicted, since the addition of a few per cent more of an element or the mixture with it of one or more other elements will often absolutely reverse what seems to be already an assured property. These great changes are brought about doubtlessly by either the formation of peculiar and intricate carbides, or by the shifting of the critical points. As a rule these special elements are added to the charge like the recarburizer, and the principal ones in use to-day are nickel, manganese, chromium, silicon, tungsten, molybendum and vanadium.

Of the above substances the one most used is nickel. It is added, as a rule, to steel of medium carbon percentage, say from 0.2 to 0.5. The usual quantity added to steel that finally is to be subjected to stress, is about 3.00 to 4.50 per cent. It seems to make the steel more homogeneous than it otherwise would be, and tends to make it fibrous in structure. These qualities endear the steel with greater ultimate, elastic and shearing strength than would be realized with an ordinary steel of the same composition; yet at the same time its ductility is but slightly diminished. These properties, therefore, make it more valuable than ordinary steel when "fatigue," (repeated or alternating stress), is the dominant factor. Though harder than ordinary steel it is, however, readily machined. An amount of 3.50% reduces the critical point (on cooling) by about 170° F and this becomes still more as nickel is added. Thus instead of the change of iron from gamma to alpha form being complete at 1290° F, as should be the case with ordinary steel, it now does not complete the transformation until a temp. of 1120° F is attained. If the nickel is increased to 25% the change does not take place except at a temperature below that of the atmosphere. In other words a steel of 25% nickel would be retained in its original state of solid solution after it had cooled; and obviously it would be non-magnetic. A still more peculiar characteristic of steels with less than 25% nickel is that this point of transformation for cooling is not reversible on reheating; that is to say, the metal is not turned back into solid solution at the same temperature. For example, a 20% nickel steel will be decomposed in cooling, at about 212° F, but it will take on reheating a temperature of about 1150° F to turn it back again into solid solution. The nickel of these steels seems to be dissolved in the ferrite and cementite, the greatest percentage being found in the ferrite. Nickel steels of low carbon composition do not take on a material hardness, when quenched, and hence if a hard surface is desired the stock is usually pack hardened, giving us, in this case, the hard surface sought after with a tough interior as well.

Manganese when over 1% makes the metal somewhat brittle, and between 4 and 5% it is extremely fragile; yet when increased beyond 7% it results in a hard and ductile material, while with 12-15% the maximum strength and ductility are attained. Water quenching of this material increases these properties in which respect the results are the opposite of what would occur with like treatment to a carbon steel. This alloy is extremely hard and it cannot be annealed, so when parts of this material are wanted they are usually cast, and grinding takes the place of machining. It is not favored with a high

elastic limit. Its extreme hardness is due in part to the forms in which the manganese is combined, in the steel, but more particularly to the austenite state of the metal, a condition brought about because the transformation point on cooling is below atmospheric temperature, thus leaving the steel in this primarily hard condition of solid solution. Little is known about the reversibility of the critical points.

Chromium acts as a hardener of steel because of the retarding action that it seems to produce upon the critical points for cooling. When quenched the steels are therefore quite hard. In proportions of 1.0 to 2.0% the resulting elastic limits are high. It is often used in combination with nickel.

Silicon tends to aid carbon in its hardening action, and also makes for a fibrous material. Steels of very great magnetic properties are made by proper addition of this element.

Tungsten and molybendum are the chief elements in the manufacture of the modern high speed steels, one per cent of the latter being as effective as two per cent of the former in producing the peculiar properties common to these steels, whose most important characteristic is that of "red hardness" or the ability of the stock to remain hard even though heated to redness. In other words a red heat does not decompose the solid solution. In these steels the critical range for cooling begins at about 1300° F and spreads out down to a temperature of about 600° F. By heating these steels in the neighborhood of 2000° F and cooling moderately fast, the critical change is prevented and the metal is retained in the condition of austenite.

Vanadium is an element but recently employed in the manufacture of alloy steel. Small amounts only seem to be necessary to confer important and peculiar properties upon the metal. It probably forms complex carbides, which in turn confer upon the steel a high elastic strength and at the same time great toughness. This element evidently serves as a scavenger for the oxygen and prevents segregation because of this quieting action.

One copy del. to Cat. Div.

SFP 8 10,6